Compact Circularly Polarized Low-Profile Agility GPS Antenna Based on Liquid Crystals

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Abstract

In this article, the design of a novel compact circular-polarization (CP) microstrip agile antenna based on Liquid Crystals (LCs) is presented. LC provides the all-in-one solution for such integration approach in terms of high quality dielectric for high performance multiband passive design and increases the peak gain and low insertion loss for GPS antenna. To benefit from LC anisotropy and thus obtaining frequency agility, a bias voltage is applied. The antenna is CP by means of the single feed technique with a truncated segment set to the edge of the patch with two orthogonal pairs of irregular and unsymmetrical slits. The simulated results are compared with experimental data, and good agreement is obtained..

Keywords

Liquid Crystals; GPS Antenna; Circular-Polarization; Agile Structure

Introduction

Mobile communications have been indispensable in modern life. There are various communication systems, such as the global positioning system (GPS) (Lin et-al, 2005), implemented to meet various needs for more agility compact antennas (Missaoui et-al, 2011; Missaoui et-al, 2012; Tentzeris et-al, 2004) The shortage in the available frequency spectrum for radio communications and the requirement for more functionality in smaller volume increase demand for reconfigurable components. Depending on the device requirements there are different possible solutions like tunable dielectrics to design agile RF components (Palazzari et-al, 2004). For decades, enormous efforts have been made on the utilization of new materials which have a better functionality. Among these materials, liquid crystals are potentially useful. LCs are organic materials that exhibit a state of matter whose properties lie between those of a conventional liquid and those of a solid crystal. An LC may flow like a liquid, but its molecules show a certain degree of ordering (positional and/or orientational), which gives them optical properties such as birefringence. In addition, they can be reoriented upon the application of a small external electric field. This is the basis of their great success as materials for the design of programmable optoelectronic components (Jewell et-al, 2005). Agile materials and technologies based on LCs offer a line of tunable passive microwave components such as varactors, phase shifters (Missaui et-al, 2011), filters and tunable matching networks, suitable in phased-array antennas, e.g. for automotive radar sensors, in reconfigurable (frequency-agile) radios, e.g. in mobile communication systems with multiband operation or RFID systems (Rao et-al, 2005). LC has a unique combination of properties as follows, : excellent electrical properties up to mm waves (Gaebler et-al, 2009), the trend towards these commercial microwave applications involves a demand for cheaply integrated, compact devices with both, high tunability and performance. Starting with some applications and physical fundamentals, this paper has proposed and investigated the design for a compact, low-profile agility GPS antenna that operates at both the conventional civilian frequency of 1575 MHz, increasing the peak gain and low insertion loss. The well know method of producing a single feed CP operation of the square microstrip antenna with two pairs of orthogonal slits at the edges is widely used in single patch and array designs (Sharma et al-al, 1983). The presence of slits in this antenna is a way to increase the surface current path length compared with that of the conventional square patch antenna.

Properties of LCs

LC science and technology now underpins a wide

variety of products, from large industrial displays to a wide array of consumer electronics both in homes and offices. Non-display applications of LCs in optical communication, nonlinear optics, data/signal/image processing and optical sensing are also receiving increased attention. Due to their unique crystalline phase characterized with the partial order of their constituent molecules along with physical fluidity, LCs can be easily incorporated into desired configurations for a variety of device applications. The large anisotropy of LCs, allows for realisation of external control over the optical properties of LC based devices, which makes LC materials suitable for the implementation of tunable photonic devices for both optical communications and optical sensing systems.

In order to describe the operating mode of the agile GPS antenna, the microwave properties of the LCs are presented. The main property of the LC in the microwave range is the dielectric anisotropy due to the application of a static electric or magnetic field. The further explanations are related to nematic LCs; which have so far shown the best dielectric properties at microwave and mm-wave frequencies (Mueller et-al, 2004).

LCs are specified by different phases that determine the state of the material , varying from solid state to a liquid state and depending on their temperature. In this study, LCs are used in the nematic phase, where the molecules float around as in the LC phase, but still ordered in their orientation (de Gennes et-al, 1974). The nematic phase (Tentillier et-al, 2004; Singh et-al, 2000) is of great interest because of the dielectric anisotropy that permits the frequency agility. Anisotropy is then defined as the difference between parallel and perpendicular permittivities and ensues from the following relation:

$$\Delta\varepsilon'_{reff} = \varepsilon'_{reff\,//} - \varepsilon'_{reff\,\perp}, \tag{1}$$

Where $\varepsilon'_{reff\,//}$ and $\varepsilon'_{reff\,\perp}$ are, respectively, the parallel and perpendicular relative dielectric permittivities.

As shown in Fig. 1, the director vector $\vec{n}$ has the same direction as the nematic LC molecules. A parallel permittivity $\varepsilon'_{reff\,//}$ of the molecules occurs for a microwave field parallel to the director $\vec{n}$, whereas a perpendicular permittivity $\varepsilon'_{reff\perp}$ is effective for a microwave field perpendicular to the director $\vec{n}$. The result of the application of a sufficiently large control voltage to LC is to align the LC along the electric field due to the control voltage. This LC alignment is nearly parallel to the microwave electric field because the transmission mode of the microstrip line is quasi-TEM. On the other hand, if the control voltage is removed (changed to 0 V), the LC becomes aligned in the direction determined by the alignment layers, which is perpendicular to the microwave electric field.

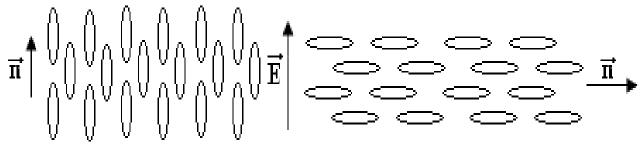

FIG. 1 CONFIGURATION MATCHING THE PERMITTIVITY $\varepsilon'_{reff\,//}$ AND $\varepsilon'_{reff\perp}$

Studies over the last two decades have also conclusively demonstrated their unusually large electro- and all-optical (i.e., nonlinear-optical) response associated with the field induced director axis reorientation. These unique optical properties, in addition to their compatibility with almost all technologically important optoelectronic materials and their fluid nature, make them preferred candidates for incorporation into nanostructured (electrically or all-optically) tunable materials/devices.

Design and Simulation for the Compact CP Microstrip Antennas Based on LCs

Conception of a Compact CP Microstrip Antennas Based on LCs

Various square patch antennas have been made in view of embedding suitable slots in the radiating patch. The first designed device (Fig. 2 (a)) contains a nearly square patch antenna. Fig. 2(b) (Qais et-al, 2005) shows the square microstrip antenna with two pairs of orthogonal slits. The presence of slits in this antenna is a means to increase the surface current path length compared with that of the conventional square patch antenna.

As Fig. 2c (Jawad et-al, 2008) shown the slits now have irregular structures. The dimensions of each pair of slots have been optimized to meet the GPS antenna design requirements. A single 50 probe feed has been used to support producing the RHCP requirement of the GPS antenna radiation pattern. The location of this probe has found to be dependent on the slits dimensions.

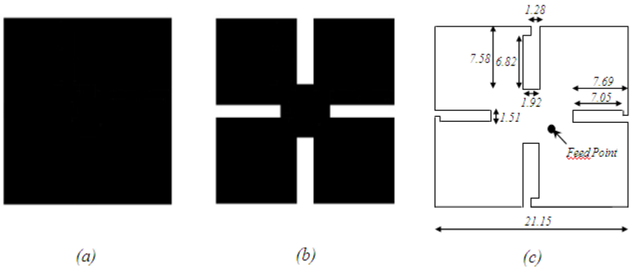

FIG. 2 (a). THE NEARLY SQUARE PATCH ANTENNA, (b). NEARLY SQUARE PATCH ANTENNA WITH TWO PAIRS OF ORTHOGONAL SLITS, and, (c). NEARLY SQUARE PATCH ANTENNA WITH TWO ORTHGONAL PAIRS OF IRREGULAR AND UNSYMMETRICAL SLITS

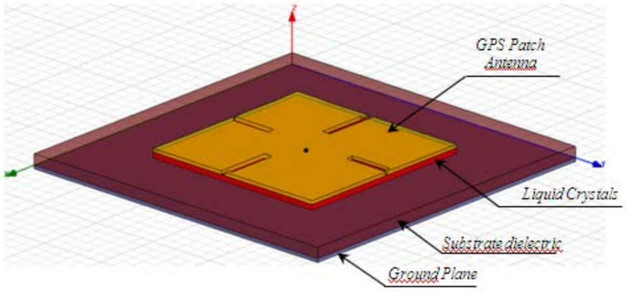

FIG. 3 DESIGN OF THE COMPACT CP SQUARE GPS ANTENNA WITH TWO ORTHOGONAL PAIRS OF IRREGULAR AND UNSYMMETRICAL SLITS BASED ON LCs

The design of the nearly square patch antenna with two orthogonal pairs of irregular and unsymmetrical slits based on LCs is shown in Fig. 3. In this configuration, the cavity into which the LC is inserted by capillarity with a dielectric constant permittivity of $\varepsilon_r = 2.9$ and a loss tangent of 0.002. The substrate dielectric constant ($\varepsilon_r = 2.2$) and height (h =1.58 mm) of substrate from ground plane are used. The antenna is CP by the single feed technique with two orthogonal pairs of irregular and unsymmetrical slits. The GPS patch antenna has a side length of 21.15 mm.

The calculations of the square microstrip antenna length are based on the transmission-line model (I. J. Bahl et-al, 1980). The width w of the radiating edge, which is not critical, is chosen at first. The length L is slightly less than a half wavelength in the dielectric. The precise value of the dimension L of the square patch has been calculated using the expression (I. J. Bahl et-al, 1980; M. Ammam et-al, 1997).

$$L = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad (2)$$

Where ε_{eff} is the effective dielectric constant and ΔL is the fringe factor.

The following table presents the electric specifications of the GPS antenna.

TABLE 1 PERFORMANCE OF THE GPS ANTENNA

Parameter	Specification
Frequency	L1:1575.42±2 MHz Minimum, ±10 MHz desired
Gain	4dB-5dB
Polarisation	Right hand circular polarization (RHCP)
Axial Ratio	3dB or better nominal
Input impedance	50 Ω
Physical dimension	Side lengths (29.05, 40.4) mm height < 1.58 mm

The CP is used on the GPS signal to avoid Faraday rotation problems associated with L-band propagation through the earth's ionosphere. The signal transmitted from the satellites has a right-hand CP and, therefore, the terminal antenna must also use RHCP (Right-Hand Circular Polarized) in order to have the maximum received signal strength. CP typically has the drawback of being slightly more difficult in its producing than simple linear polarization.

Simulation of a Compact CP Microstrip Antenna Based on LCs

The high frequency structure simulator (HFSS) was used to optimize the dimensions of the antenna to obtain a resonant frequency of 1575 MHz. Fig. 4 depicts the results of simulated and calculated return losses with and without LC and the dielectric permittivity is 2.9, it can be observed that return loss achieved -20 dB from 1.55 to 1.6 GHz. The resonance frequency variation (ΔFr) between with and without LC is 4.41 MHz corresponding to a frequency agility of 0.28%. The bandwidths simulated and calculated of the GPS antenna at -10 dB are respectively 27.5 MHz (1.74%) and 13.75 MHz (0.87%).

These frequency errors between the results are mainly due to radiation outside of the substrate which is not taken into account in the simulation. Also, these errors may be due to losses in the conductor of the antenna.

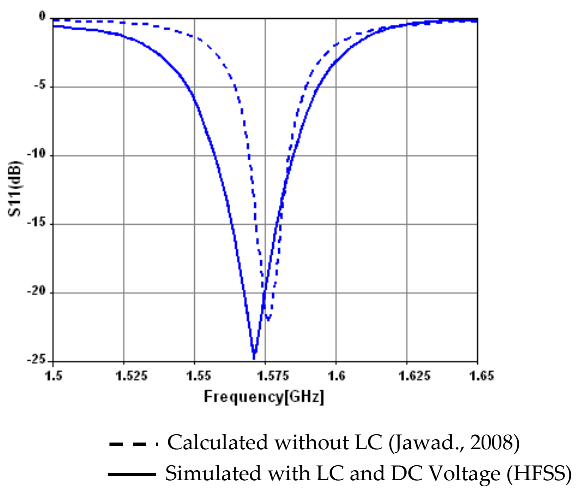

FIG. 4 SIMULATED AND CALCULATED RETURN LOSSES

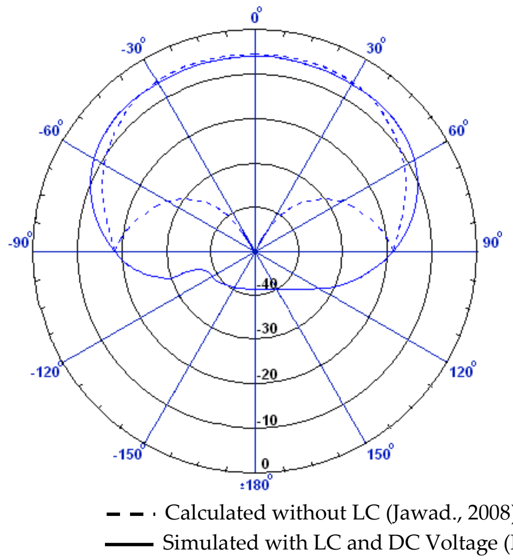

FIG. 5 SIMULATED AND CALCULATED E-PLANE RADIATION PATTERNS OF THE GPS ANTENNA AT 1575.42 MHz

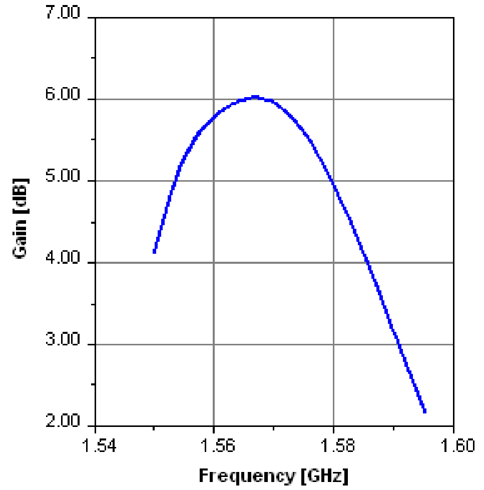

FIG. 6 SIMULATED GAIN OF THE GPS ANTENNA

Fig. 5 depicts the simulated and calculated radiation patterns of the GPS antenna. The radiation patterns of simulated and calculated are nearly the same plane; and it is clearly seen from the radiation pattern comparison that, the peak gain with and without applied DC Voltage is respectively 6 dB and 5.5 dB, therefore, the found gain with LC is improved.

The simulated gain around the GPS L1 has been shown in Fig. 6. As implied by the gain response, the proposed antenna possesses an average gain of about more than 4 dB throughout the required bandwidth of GPS L1 antenna. The experimental result of the GPS antenna even meets the more demanding ± 10 MHz goal which is needed to receive the full encrypted GPS coded data.

Conclusions

This paper presents the fundamentals of LC material and its applications for reconfigurable GPS antennas. The structure based on the coaxial feed line configuration has been designed and simulated. The observation of the results confirms the potential frequency agility and increase the peak gain of the device in which LCs are employed. This agility was obtained by varying the LC dielectric permittivity, as well as by applied DC voltage. The accuracy of simulation was verified by comparison with experimental data.

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